UWB Leaky Lens Antenna as an Improved Performance Emitter in a THz Time Domain System

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***Abstract*— In this contribution we introduce the use of the UWB leaky lens antenna as an improved photo-conducting emitter for a THz time domain system. The UWB antenna presents nearly constant impedance and directive symmetric patterns over a decade of frequency bandwidth. Currently, we are working towards the fabrication of a demonstrating prototype.**

I. Introduction

A recent innovation in the terahertz spectroscopy field is the fast pulsed optical time domain spectrometer (THz TDS). This system uses femtosecond optical pulses to generate electrons in a photoconductive switch [1]. A modest DC voltage (20-100V) sweeps up the electrons, applies them to an antenna, and radiates a THz pulse into free space. The THz energy is passed through an intervening sample (gas, liquid or solid) and collected with another photo-conductive antenna (or it can be also collected on a small electro-optic crystal). At the same time a portion of the original optical pulse is beam splitted and passed through an optical delay line before illuminating the same receiver antenna. This portion of the pulse is used to sample the change in THz intensity of the beam passing through the sample as the optical delay line is translated. The resulting interferogram is a map of the THz electric field versus time for each pulse as it propagates through the sample.

The system performances rely on the antenna response, both in terms of radiation efficiency and time domain pulse distortion, since the frequency spectrum of the TDS system is proportional to the antenna spectral response [2]. Resonant antennas will generate a peaked spectral response at the antenna resonant frequency. Most of the TDS systems use an Austin switch consisting on a very small dipole-like antenna. If the dipole is smaller than the resonance, it will generate a broad spectrum, but with a very low radiation efficiency due to the fact that the impedance will be practically imaginary. Another important aspect with such TDS antennas is that they are coupled to an optical system in order to perform the spectroscopic analysis. This means that the antenna needs to be directive.

UWB antennas have been extensively study in the microwave regime, but they are usually dispersive, or not directive. Recently, a revolutionary new UWB antenna has been proposed [3]. The antenna has been demonstrated to be a pulse preserving antenna in the microwave regime, from 10 to 100 GHz [4]. In this work, we want to propose the use of such an antenna to improve the performances of standard TDS systems. In order to compare the new UWB antenna with several antenna geometries, we have performed a time domain analysis of several antenna geometries with the commercial tool MWS CST.

II. Standard Photo-conducting Antennas

Most of TDS systems use an Austin Switch as photo-conductive antenna, see Fig.1. The antenna is printed on a substrate and coupled to an extended hemispherical lens, also shown in the figure.

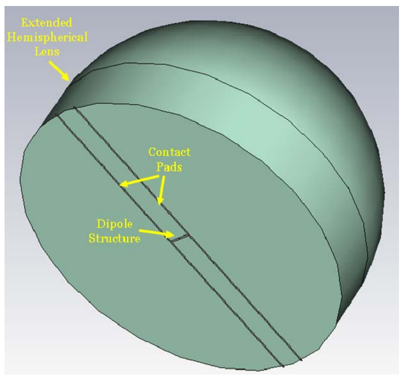

Fig. 1 Geometry of an Austin Switch Antenna.

When analyzing the TDS, most studies assumed the antenna as a point source for which the radiated electric field is directly proportional to the time-derivative of the current [5]. This does not consider the influence of the antenna geometry or the presence of the contact pads. Some studies have included the impact of antenna length incorporating the Smith model [6]. However the dispersion or impact of the contact pads is still not considered. Here we want to study the impact of the real antenna geometries on the TDS spectral and time properties in order to show the enhanced performances of the new UWB antenna. In order to do so, we have used the time domain solver of MWS CST with the several antennas radiating in an infinite dielectric medium (absorbing boundaries are used at the edges of the dielectric).

Let us first start with a simple resonant antenna of 100µm length and 5um width. Figure 2 shows the input impedance of such antenna for a bandwidth from 100GHz to 3THz. We can see the picks in the impedance associated to multiple resonances. The Austin switch uses two contact pads as shown in the insets of the figure. Theses pads shift the resonance of dipole towards lower frequencies, and can also change the pick impedance depending on the pad actual width.

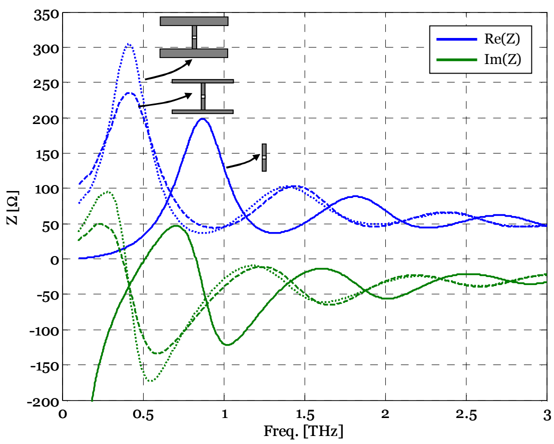

Figure 2: input impedance of a resonant dipole (100µm) and two Austin Switches with the same central dimensions and two different contact pad widths (5 and 20 µm).

Moreover, the pads also change the distribution of the radiated field by the antenna. Figure 3 shows the variation of the electric field calculated with a probe placed at a distance of 950µm from the antenna aperture (see the inset of the figure) inside the dielectric. The dips and maximums are related to the radiation diagram of the antenna, and therefore the current distribution (for example, there is a null of field at broadside at 1.6THz when the dipole length is equal to the equivalent wavelength). The contact pads will alter the current distribution of the antenna, as it can be seen in Fig. 4, where the field distribution at the antenna aperture is shown. One can clearly see the difference in the antenna current distribution.

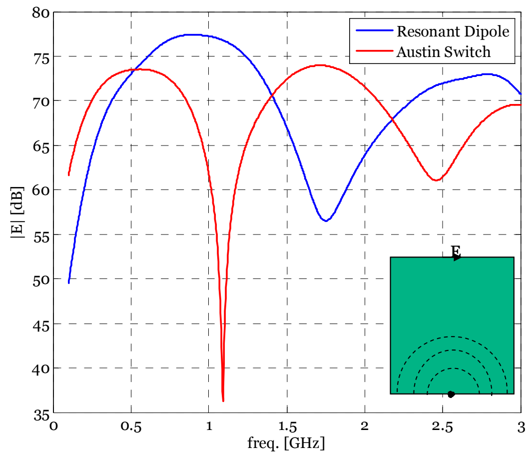

Figure 3: electric field probe at 950 µm from the antenna plane for the resonant dipole and the 20 µm pad cases of Fig. 2.

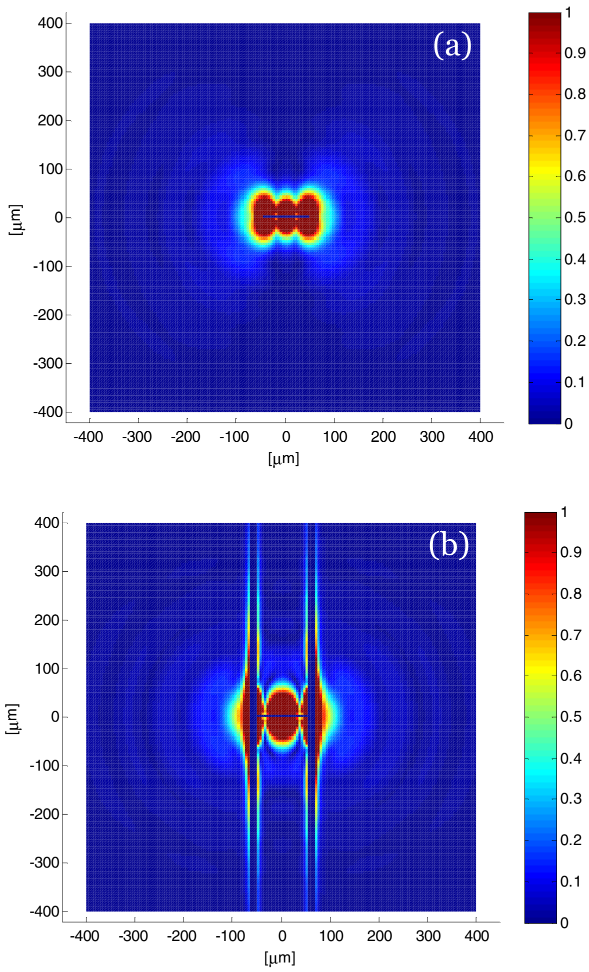

Figure 4: electric field at the antenna plane for the same cases than Fig. 3 (1.5THz): (a) resonant dipole and (b) Austin switch

In an actual TD system, the photo-conducting antenna excites a silicon lens as shown in Fig. 1. In this case, the distribution of the peaks and minimums of the TD spectrum may not coincide with the ones shown in Fig.3 because they will also depend on the lens geometry. In order to have a complete characterization of the system, one should also include the analysis of the lens. Even so, the field in Fig. 3 serves as a comparison parameter between the different antenna geometries.

III. UWB LEAKY LENS ANTENNA

The new emitter concept utilizes a classic THz generating Austin switch that excites an electrically long radiating slot. A leaky wave with nearly constant propagation constant over a large bandwidth can propagate in a long slot printed in between two infinite mediums [7]. This antenna will have already very good impedance in terms of the frequency; see Fig. 5; and a field distribution like the one shown in Fig 6.

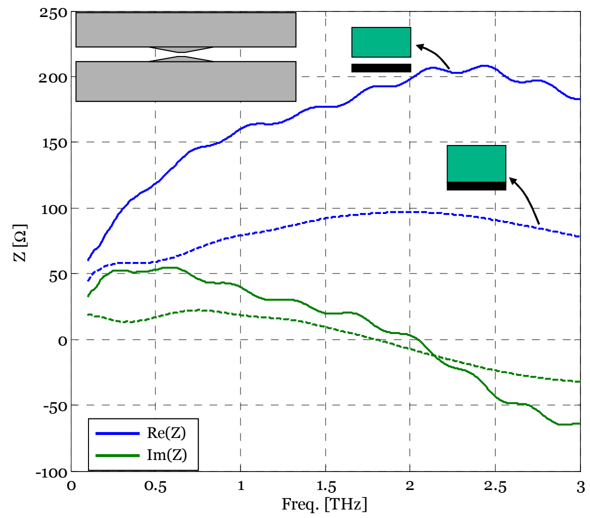

Figure 5: the input impedance of leaky wave slot (ws=50µm) and enhanced leaky wave slot by an air cavity of 25µm thick.

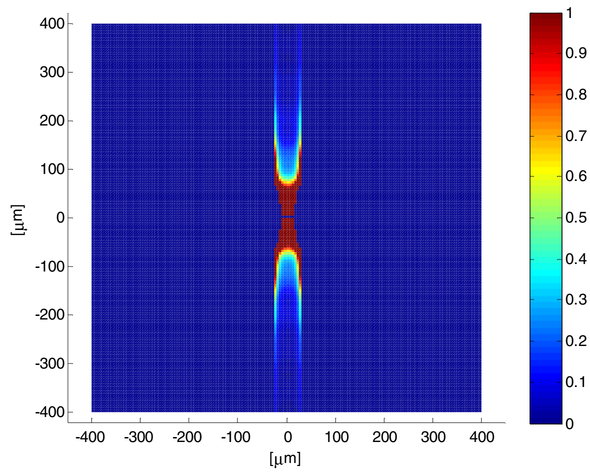

Figure 6: electric field at the antenna plane for leaky wave antenna of Fig. 3 (1.5THz).

The leaky wave antenna will provide already a field coupling pretty constant in frequency, as shown in Fig.7, thanks to the low frequency variation of the leaky wave propagation constant. This coupling is not as high as the one from the Switch because the leaky wave radiates towards large angles [3].

The new and enhanced leaky wave antenna [3] introduces an air cavity, small in terms of the wavelength, in between the ground plane and dielectric. This cavity helps to make the leaky wave point towards smaller angles increasing the field coupling as shown in Fig. 7. At the same time the low frequency dependence of the mode propagation constant and impedance is maintained (see Fig. 5).

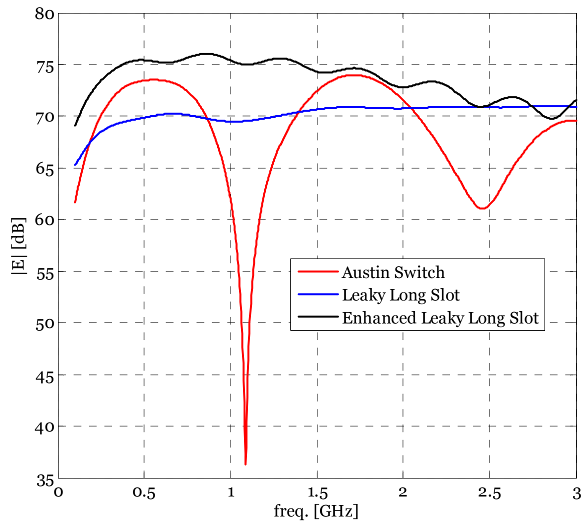

Figure 7: electric field probe at 950 µm from the antenna plane including the leaky wave antennas.

In the actual system, the enhanced leaky wave will also improve the excitation of the silicon lens because it will excite the upper part of the lens reducing the power lost into multiple reflections (that appears for large angles).

IV. PROTOTYPE FABRICATION

The new emitter concept utilizes a classic THz generating Austin switch (thin metal gap on a low temperature grown GaAs substrate excited by an applied DC voltage) that excites an electrically long radiating slot which in turn couples to a cavity excited silicon hyper hemispheric lens antenna, see Fig. 8. The silicon lens is composed of ultra-high resistivity material to reduce absorption losses in the frequency range of interest and completes the beam forming process. The hyper hemispherical lens must be custom fabricated with the appropriate excitation gap. The coupling of the slot to the cavity backed hyper hemisphere involves the formation of a special membrane wafer that keeps the region behind the slot open to the air rather than embedded in substrate material. A special wafer growth and etch-back process is being utilized to produce this portion of the circuit.

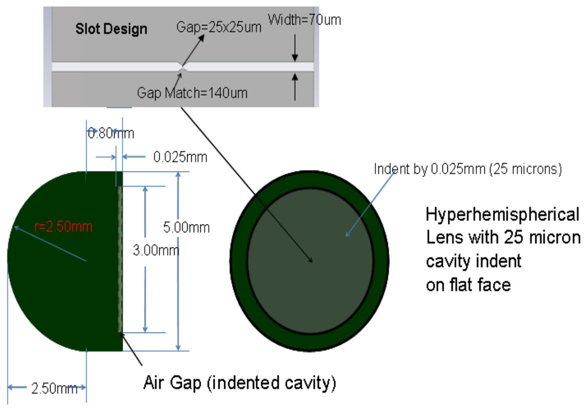

Fig.8: Enhanced Emitter Geometry: Austin switch excited slot line with associated cavity backed silicon lens antenna.

V. Conclusions

We have studied the use of the UWB leaky lens antenna as an improved photo-conducting emitter for a THz time domain system. The UWB antenna presents nearly constant impedance and directive symmetric patterns over a decade of bandwidth, improving both the impedance matching and the optical coupling of the system. In this contribution, we have compared the performances of the leaky lens antenna with standard resonant geometries by performing simulations with CST. Currently, we are working towards the fabrication of a demonstrating prototype.

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